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Abstract

Cemented carbides, referred to as hardmetals, are forefront engineering materials widely implemented in industry for chip-removal cutting tools and supporting parts. As a newly developed technology for surface modification with high precision, the application of short pulse laser may extend the utilization of cemented carbides. However, surface integrity of laser-treated materials may be affected during the ablation phenomena. These potential changes may also be relevant for subsequent coating deposition, a surface modification stage usually invoked in many cutting and forming tools. It is the objective of this work to study the influence of a previous laser treatment on the surface integrity of a cemented carbide grade, finally coated by a ceramic layer introduced by physical vapor deposition. In doing so, a nanosecond laser has been employed. Surface integrity is assessed in terms of roughness, hardness, and microstructural changes induced at the subsurface level. It is found that pulse laser can effectively remove the target material, resulting roughness being similar to that attained by abrasive grinding. Although some subsurface damage is observed, it is limited to a very shallow layer, this being thoroughly eliminated during sandblasting implemented before coating deposition. Relative hardness increase is larger for laser treated substrate than for just polished one, reason behind it being speculated to come from the sandblasting stage used for removing damaged layer.

Keywords	Cemented Carbides; Laser; Coating; Surface Integrity; Roughness; Hardness.

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Professor Xiaoyan Song

Associate Editor
International Journal of Refractory Metals and Hard Materials

Dear Prof. Song,

Please find attached the short communication entitled “Surface Integrity Assessment of Laser Treated and Subsequently Coated Cemented Carbides” that we offer for consideration as contribution to the International Journal of Refractory Metals and Hard Materials. As you may notice, this manuscript corresponds to our work presented in the WorldPM2018 Beijing last year. We have taken into consideration the format guidelines in the submitted version and I hope that you find this contribution suitable for publication in the journal. I look forward to hearing from you in the near future.

Yours sincerely,

Shiqi Fang

- Laser yielded a rising surface roughness, similar to ground HM
- Laser induced damage only exists in a very shallow sublayer
- Sandblasting before coating treatment can effectively eliminate the sublayer
- Coating implies a relevant hardness increase
- Hardness increase is more pronounced in the previously laser treated HM

Surface Integrity Assessment of Laser Treated and Subsequently Coated Cemented Carbides

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Abstract. Cemented carbides, referred to as hardmetals, are forefront engineering materials widely implemented in industry for chip-removal cutting tools and supporting parts. As a newly developed technology for surface modification with high precision, the application of short pulse laser may extend the utilization of cemented carbides. However, surface integrity of laser-treated materials may be affected during the ablation phenomena. These potential changes may also be relevant for subsequent coating deposition, a surface modification stage usually invoked in many cutting and forming tools. It is the objective of this work to study the influence of a previous laser treatment on the surface integrity of a cemented carbide grade, finally coated by a ceramic layer introduced by physical vapor deposition. In doing so, a nanosecond laser has been employed. Surface integrity is assessed in terms of roughness, hardness, and microstructural changes induced at the subsurface level. It is found that pulse laser can effectively remove the target material, resulting roughness being similar to that attained by abrasive grinding. Although some subsurface damage is observed, it is limited to a very shallow layer, this being thoroughly eliminated during sandblasting implemented before coating deposition. Relative hardness increase is larger for laser treated substrate than for just polished one, reason behind it being speculated to come from the sandblasting stage used for removing damaged layer.

Keywords: Cemented Carbides; Laser; Coating; Surface Integrity; Roughness; Hardness.

1. Introduction

Laser ablation, as an advanced surface treatment approach, is emerging in industry with the benefits to process materials hard to be machined using conventional approaches. Especially, the development of pulse laser boosts its applications as surface damage induced by traditional mechanical cutting processes or other non-traditional electrical thermal removal processes can be effectively reduced or avoided [1-2]. Laser has also been implemented for surface treatment of cutting tools. Classical tribological microstructures, such as dimples and grooves, have been produced on surfaces of cutting tools, yielding beneficial effects regarding lubrication distribution and heat transmission [3,4]. Current investigation mostly focuses on the influences of the geometrical features of the laser produced textures on the cutting tool performance [5,6]. Meanwhile, there are also studies addressing possible laser-induced damage on tool materials, such as cemented carbides. For example, surface damage, introduced during different ablation regimes (femto-, pico- and nanosecond) and parameters have been inspected and compared in recent investigations [7-9]. However, information about this subject is quite limited, particularly regarding development of texture geometry and its influence on functionality of the surface treated hardmetals.

Coating, as an extensively used surface treatment for cutting tools, is an effective approach to improve their mechanical and tribological properties, especially hardness and wear resistance [10,11]. Considering that coating is an almost compulsory final surface treatment for hardmetal tools, it seems clear that further knowledge about synergy between laser treatment and subsequent layer deposition is required [12-14]. Surface integrity, describing the surface condition of the workpiece after being modified by a manufacturing process, then becomes a vital issue, under the consideration of combining both surface treatment methods, i.e. laser and coating [15,16]. Within the context, it is the objective of this study to assess the surface integrity of a first laser-ablated cemented carbide substrate, followed by a physical vapor deposited (PVD) layer. In doing so, surface topographical features, hardness, as well as morphological and structural changes will be studied for different surface finish conditions.

2. Experiments

2.1 Materials and sample preparation

A plain WC-Co cemented tungsten carbide, here referred to as 10CoC, was studied. Microstructural characteristics and basic mechanical properties are listed in Table 1.

Table 1. Microstructural characteristics and properties of the studied cemented carbide.

Cemented Carbide Grade	Grain Size (μm)	Co (wt%)	HV (GPa)	K_{Ic} ($MPam^{1/2}$)
10CoC	0.31	10	11.4	15.8

2.2 Laser ablation and coating deposition

Ablation on the cemented carbide surface was carried out using a nanosecond set-up, combined with a 2 directional reflecting unit. The Nd:YLF laser source can emit the laser beam with the wavelength of 349 nm, the pulse duration of 5 ns and the frequency of 1000 Hz. A layer with the thickness of 10 μm was removed by the laser beams on the cemented carbide grade, using an average power level of 0.01W. Following laser ablation, an AlTiN layer was deposited on the cemented carbide surfaces using an industrial PVD installation. Prior to coating deposition, sandblasting was applied to clean the target surface. Coating layer had a thickness of 4 μm and hardness of 37 GPa.

Three different surface finish conditions, including a polished (and thus, non-laser treated) reference case, were achieved for the studied cemented carbide grade, namely:

- Polished cemented carbide surface (P)
- Polished surface being coated (P+C),
- Polished surface being machined by laser (P+L),

- Polished surface being first machined by laser, and then coated (P+L+C).

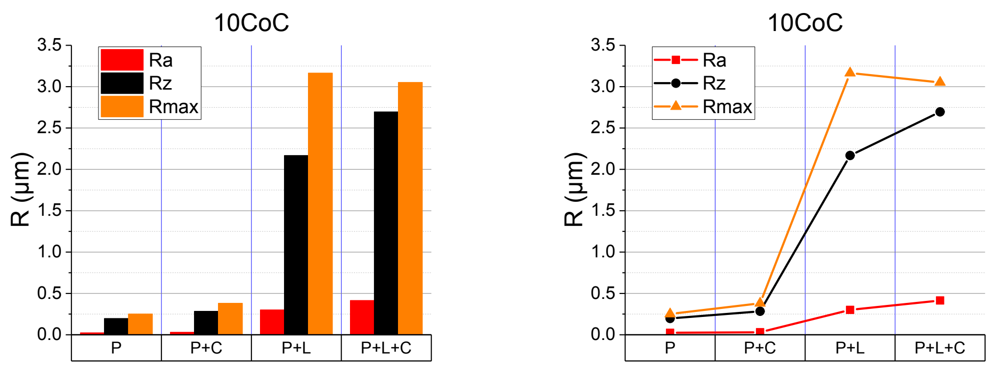
2.3 Surface integrity assessment

Surface integrity assessment mainly includes topographical, mechanical, morphological and cross-sectional characterization of the cemented carbide under different surface finish conditions. Topographical modification induced by each surface finish condition was evaluated by means of surface roughness. Three roughness parameters, i.e. arithmetical mean roughness R_a, ten-point mean roughness R_z and maximum roughness depth R_{max}, were determined using roughness tester Mahrsurf XR20 (Mahr GmbH). Mechanical properties were assessed by hardness measurement using a Vickers indenter and three different normal loads, i.e., 0.2942N, 2.942N and 29.42N. Morphological features of the surfaces were inspected using scanning electron microscopy (SEM). Cross-sectional observation was carried out using a focused ion beam (FIB) unit couple to SEM. It allowed to characterize the microstructural modification induced by laser and coating treatments.

3. Results and discussion

3.1 Roughness tests

Results of roughness tests obtained for the four surface finish conditions are summarized in Table 2 and compared in Figure 1. In general, as expected, laser-ablation is found to increase roughness values in about one order of magnitude, as compared to mirror-polished surface condition. Nevertheless, values attained are similar to those usually found in mechanically ground cemented carbides. On the other hand, coating stage is not significantly affecting surface topography exhibited by substrates before being coated.



(a) (b)

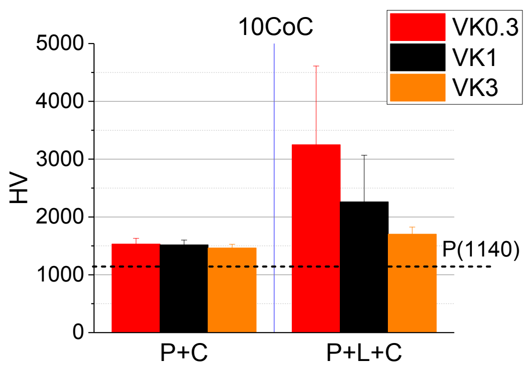
Figure 1. Surface roughness of cemented carbide with surfaces finished with different conditions: (a) details (b) change.

Table 2. Measurement of surface roughness with different surface finish conditions

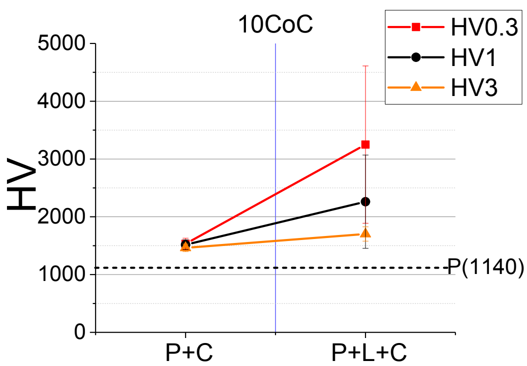
Conditions	Ra (µm)	Rz (µm)	Rmax (µm)
P	0.02	0.20	0.25
P+C	0.03	0.28	0.38
P+L	0.30	2.17	3.16
P+L+C	0.41	2.70	3.05

3.2 Hardness measurement by Vickers hardness tests

The results of hardness measurement are summarized in Table 3 and Figure 2. As it is shown in Figure 2(a), surface treatments increased hardness baseline measured for the reference polished cemented carbide. Very interesting, laser-treated material exhibits a larger improvement. However, relative changes are variable depending on the magnitude of applied load for L+C condition. Considering that such variable response, as a function of applied load, is not discerned for the just coated one, it would imply that changes are associated with the existence of a narrow subsurface layer with compressive residual stresses, speculated to come from the sandblasting stage required for removing the region affected by previous laser ablation.



(a)



(b)

Figure 2. Comparison of the Vickers hardness of the cemented carbide surfaces finished with different laser conditions: (a) details and (b) change.

Table 3. Measurement of Vickers hardness on the cemented carbide surfaces finished with different conditions.

Conditions	HV0.3	HV1	HV3
P	1140(nominal value)		
P+C	1532.0	1517.0	1463.0
P+L+C	3249.4	2261.4	1702.2

3.3 Characterization of surface morphology

Surfaces finished with different conditions exhibited different morphological features. As a result, the deposited TiAlN coatings showed also different morphological aspect on these surfaces. For the non-laser machined cases as shown in Figure 3(a,b), the coating layer grew regularly on the target surface. As a consequence of the laser ablation, the obtained surface morphology changes significantly. It was covered by a layer of molten and redeposited material (Figure 3(c)). This modified layer was completely removed because of sandblasting, prior to coating deposition. However, this mechanical treatment did not yield similar roughness, and this is reflected at both surface (top view) and subsurface (interface in cross-section view) levels. As a result, coating in previously laser ablated (and sandblasted) material, exhibits a bubble pattern, as shown in Figure 3(d). This is clearly different from the aspect exhibited by the layer in the reference condition, and should be related to nucleation and growth issues, whose investigation was out of the scope of this study.

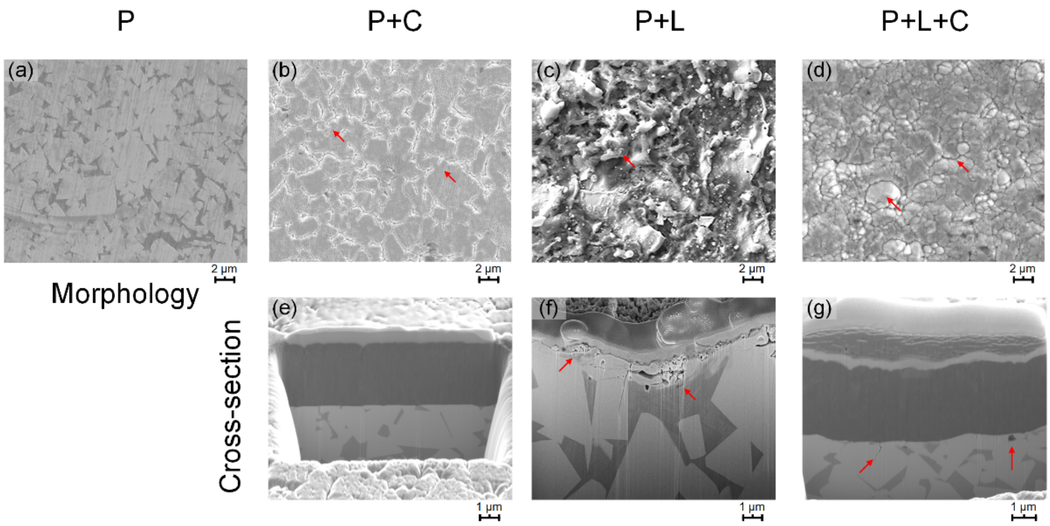


Figure 3. SEM-FIB micrographs showing surface topography and cross-section of the studied cemented carbide grade with different surface finish conditions, i.e., (a) polishing, (b,e) polishing and coating, (c,f) polishing and laser ablation, and (d,g) polishing, laser ablation and coating.

According to the cross-sectional analysis, it is remarkable that coating layers are deposited with a high parallelism on the non-laser machined surface. Between the coating layer and the cemented carbide surfaces, no obvious damage, such as cracks and pores, is observed for the non-laser ablation cases (Figure 3(e)). However, relevant surface damage has been induced after the laser ablation beneath the laser machined surface (Figure 3(f)). Ablation action seems to be heterogeneous, and then possibly different for each of the constitutive phases. Re-deposition layer of the molten material is clearly identified, and relatively thin, i.e. of less than 0.5 µm. In general, laser-induced thermal damages such as cracks and pores are found within this very shallow surface layer. Looking at Figure 3(g), it is clear that sandblasting results to be an effective route for removing such thin and undesirable laser affected zone.

Furthermore, in such figure it can be observed that coating layer grew along with the surface topography from the bottom to the top. The top surface topography of the coating layer in general maintains that of the cemented carbide grade, this being reflected in roughness values measured for both coated conditions.

4. Conclusion

In this work, surface integrity of a cemented carbide grade, finished by laser ablation and sequential coating deposition, was assessed in terms of surface roughness, hardness, morphological changes and microstructural modification. The following conclusions may be drawn:

- Laser ablation induced a rising surface roughness, as a consequence of the molten and redeposited layer. However, roughness level attained is similar to that usually found in ground cemented carbides.
- Damage induced by laser ablation exists in the form of cracks and pores, but it is localized in a very shallow subsurface layer.
- Final coating implies a relevant hardness increase, this being more pronounced in the previously laser treated material. The fact that hardness rise varies as a function of applied indentation load, would point out residual stress effects concentrated in a tiny subsurface layer. Possible reason for this behavior may be linked to the sandblasting stage, conducted for removing undesirable laser affected zone.

Acknowledgement

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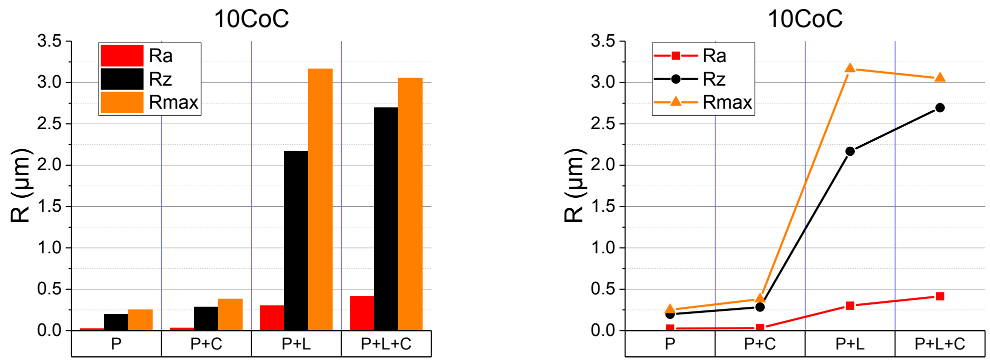

(a) (b)

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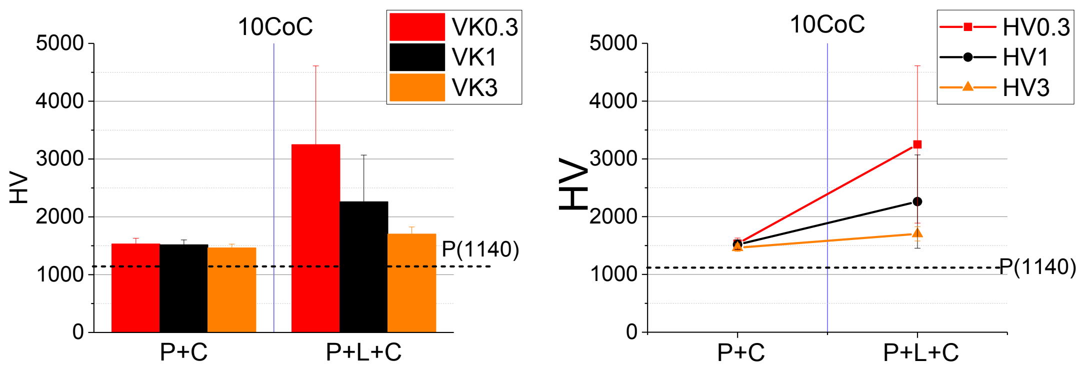

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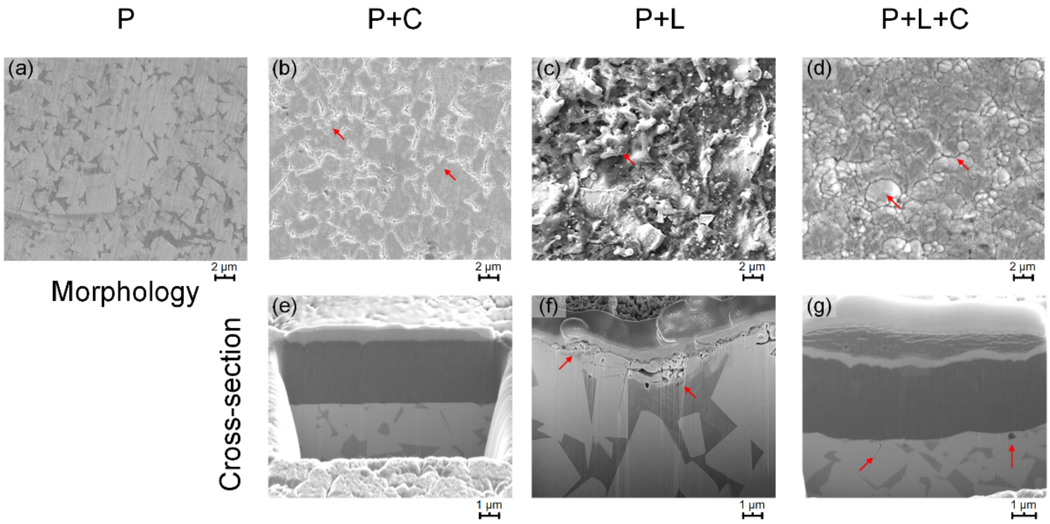

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